Preprint
UCRL-JC-140091

The Quench Sensitivity of Hot Extruded 6061-T6 and 6069-T6 Aluminum Alloys

S.C. Bergsma, M.E. Kassner, X. Li, and R.S. Rosen

This article was submitted to
3rd International Conference on Processing and Manufacturing Advanced Materials, Las Vegas, NV, December 4-8, 2000

August 8, 2000

U.S. Department of Energy

Lawrence
Livermore
National
Laboratory

The Quench Sensitivity of Hot Extruded 6061-T6 and 6069-T6 Aluminum Alloys

S.C. Bergsma[a], M.E. Kassner[b], X. Li[b], and R.S. Rosen[c]

[a]*Northwest Aluminum Company, The Dalles, OR 97058 USA*
[b]*Department of Mechanical Engineering, Oregon State University, Corvallis, OR 97331 USA*
[c]*Lawrence Livermore National Laboratory, Livermore, CA 94550 USA*

Abstract

The purpose of this study is to investigate the quench sensitivity of mechanical properties of hot extruded 6061 and 6069 aluminum alloys. The relationship between mechanical properties and quench delay time at various temperatures between 200-500°C was determined. It was concluded that the 6069-T6 was somewhat more quench sensitive than 6061, which may be consistent with the composition difference.

Introduction

The mechanical properties of 6069 were extensively discussed by the authors in [1,2]. The objective of this study was to determine the quench sensitivity of the new alloys 6069, especially as compared to 6061. That is, on rapidly cooling from the solution annealing temperature by quenching, any reduction in the cooling rate translates to longer times at intermediate temperatures where "uncontrolled" nucleation can occur and lead to lower T6 properties subsequent to controlled or optimized aging. The mechanical properties response varies for a given, decreased, cooling rate depending on the alloy composition. Gullotti et al. [3] and others [4] found that for the 6XXX alloys, those that had higher Mg, Si, Mn, Cr, and Zr were more likely to have relatively accelerated $MgSi_2$ precipitation leading to diminished T6 mechanical properties. Mondolfo [5] reports that Cu increases quench sensitivity, but Zoller et al. [4] find Cu actually alleviates quench sensitivity somewhat. The new 6XXX alloy 6069 has been demonstrated to have superior T6 fatigue, tensile and fracture toughness properties over 6061 [1,2]. However, the improved properties are provided in association with alloy additions Cr, Mg, Si, Mn that may render 6069 quench sensitive (and Cu for which the effect is uncertain). Thus, this investigation assessed the quench sensitivity of 6061 and 6069, both prepared identically by air slip direct chill casting (ASDC) and hot extruded. Both were solution treated at the same temperature and "quenched" into salt baths at various temperatures for various times followed by a water quench. The times at temperatures for a fixed deterioration (e.g., 5%) of T6 tensile (yield stress and ultimate tensile stress) were determined. The 6061-T6 quench sensitivity would be compared with other 6061-T6 quench sensitivity studies on direct chill cast (DC) ingot hot rolled into sheet [3].

Experimental Procedures

The 6061 and 6069 aluminum alloys used in this study were extruded at Anodizing Inc. (Portland, Oregon) from Air-Slip™ Direct Chill Cast (ASDC) ingots provided by Northwest Aluminum Company. 6061 ingot was extruded into solid flat bar with thickness of 9.53 mm and width of 38.1 mm. 6069 (228.6 mm diameter) ingot was extruded into solid round bar of 38.1 mm in diameter.

The 6069 ingot was annealed before extrusion. The compositions of 6061 and 6069 aluminum alloys used in this study as well as 6061 sheet from [3] are listed in Table 1.

The tensile specimens of 6061 and 6069 aluminum alloys of this study were cut randomly along extrusion direction and machined into round specimens with 2.54 mm in diameter and 10.2 mm gage length. The specimens were solution heat-treated at 566°C for 1.5 hours in a case furnace with accuracy of ± 1.5°C, quenched to various temperatures (200-500°C) into a molten salt bath for various times (3-200 seconds) and then 21°C water quenched. The (molar) composition of molten salt used in the temperature range of 300 to 500°C was 18.3% KCl, 50.4% LiCl, 8% NaCl and 23.3% RbCl. The (molar) composition of molten salt used in the temperature range of 200 to 300°C was 56% $AlCl_3$, 7% KCl and 37% LiCl. Thermocouples were placed inside the center of a "control" specimen and the time was recorded when the temperature of thermocouples was within 3°C of molten salt. The precipitation treatment for extruded 6061 and 6069 specimens was 185°C for 8 hours.

Results and Discussion

Figures 1 and 2 show the relationship between mechanical properties (yield stress, UTS and elongation) of extruded 6061-T6 and 6069-T6 aluminum alloys and the delay quenching time at various (isothermal) temperatures (200-500°C). It is found that the (0.2% offset) yield stress and UTS of both alloys decreased as the hold time increased at a given isothermal temperature. It is also observed that at a given hold time the strength of both alloys decreased as isothermal temperature decreased (from 500-350°C) and then increased again (from 300-200°C). The largest decreases in strength (yield and UTS) are observed at isothermal temperatures of 350-390°C for extruded 6061 and 6069. It is also observed that elongation (%) slightly increased as hold time increased especially at isothermal temperatures of 300-390°C.

Based on these results, the time-temperature curves at 95% of maximum (no delay) yield stress and UTS for extruded 6061-T6 and 6069-T6 aluminum alloys are illustrated in Figure 3. The data of 95% of maximum strength were sometimes interpolated from the strength data. It is observed that extruded 6061 allows more time for a decrease to 95% of maximum strength than extruded 6069 at a given isothermal temperature. This indicates that mechanical properties of extruded 6069 are more sensitive to quench-rate than those of extruded 6061 as expected based on higher levels of Mg, Si, Cu and Cr reported in Table 1. The figure also reports other data of 6061 [3,4]. The increased amount of magnesium, silicon and chromium may increase Mg_2Si concentration and nucleation rate, which is consistent with other studies [3]. The discrepancy between the 6061-T6 of

Table 1. The Composition of Extruded 6061 and 6069 Aluminum Alloys used in this Study as well as 6061 Sheet [3]

	Element, % wt.									
	Si	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Ti**	**V**	**Ga**	**Zn**
Extruded 6061	0.65	0.23	0.23	0.02	0.89	0.06	0.024	0.01	0.01	—
Extruded 6069	0.88	0.30	0.71	—	1.40	0.22	0.032	0.11	0.02	0.01
6061 Sheet [3]	0.66	0.38	0.23	0.12	0.98	0.12	0.014	—	—	0.07

this and the earlier study by Gullotti et al. [3], particularly at low temperatures, is not understood. From a practical viewpoint, with continuous cooling, the behavior at temperature below the "nose" or times for fixed reductions in tensile properties, is less relevant. It is, nonetheless, curious that the 6061 of the present study shows more quench sensitivity, since the Cr, Mg, Mn, Si are all (slightly) *lower* than that of the Gullotti study. Perryman et al. [6] found that Zn may enhance quench sensitivity in Al-Mg alloys, but again, Zn is lower in the 6061 of the present study.

Conclusions

1. 6061 and 6069 extruded aluminum alloys were solutionized and quenched to various temperatures in salt baths between 200 and 500°C for various times, followed by water quenching. The strength of extruded 6061-T6 and 6069-T6 alloys decreased as isothermal temperature decreased from 500-350°C and then increased again from 300-200°C for fixed times at temperature. The largest strength (yield and UTS) decreases occurred at isothermal temperature of 390°C and 350°C for extruded 6061-T6 and 6069-T6, respectively.

2. Time-temperature curves at 95% of maximum yield stress and UTS for extruded 6061-T6 and 6069-T6 aluminum alloys indicate that mechanical properties of extruded 6069 are more sensitive to quench-rate than those of extruded 6061.

3. The increased quenched sensitivity appears to be due to increased amount of magnesium, silicon, manganese and chromium which may increase the Mg_2Si concentration and nucleation rate.

Acknowledgments

This work was performed as part of the Oregon Metals Initiative Program which is funded through partnership with the Oregon Economic Development Department and the Northwest Aluminum Company, and under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

References

[1] S.C. Bergsma, M.E. Kassner, X. Li, M.A. Wall, Mater. Sci. and Eng. A254 (1998) 161-171.

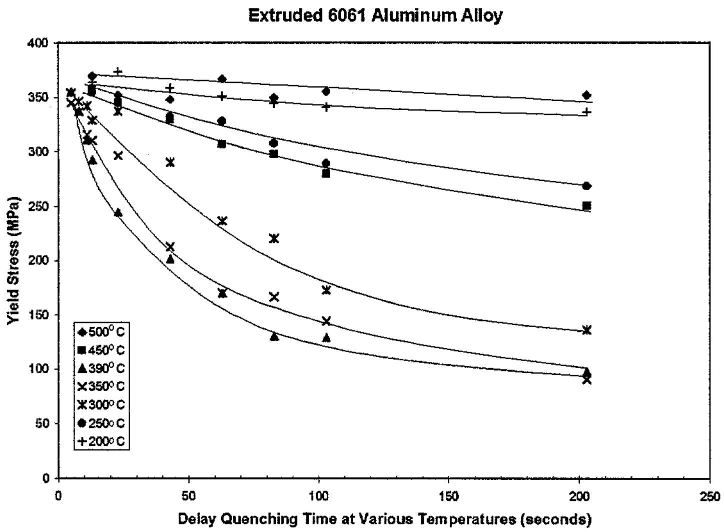
[2] F.J. MacMaster, K.S. Chan, S.C. Bergsma, M.E. Kassner, Mater. Sci. and Eng., in press.

[3] D.V. Gullotti, J. Crane, W.C. Setzer, International Extrusion Technology Seminar, Atlanta, 1977, p. 249.

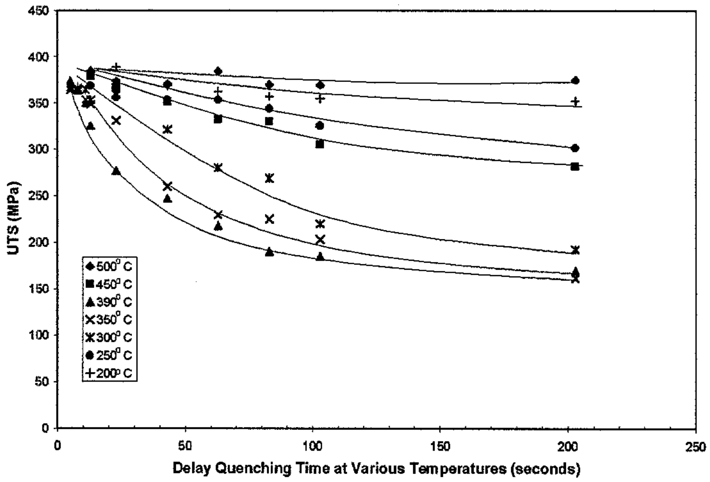
[4] H. Zoller, A. Ried, Z. Metall. 62 (1971) 354-358.

[5] L.F. Mondolfo, Aluminum Alloys: Structure and Properties, London, Butterworths, 1976.

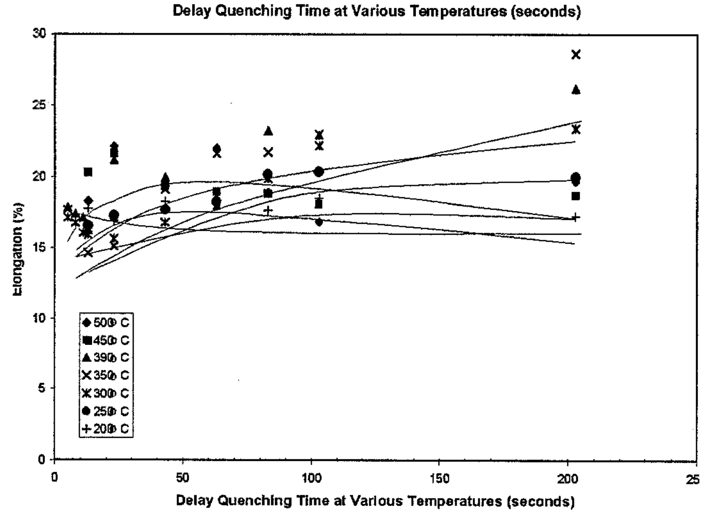
[6] E.C. Perryman, G.B. Brook, JIMMA 32 (1995) 19-34.



(a)



(b)



(c)

Figure 1. The effect of delayed quenching on the 6061-T6 (a) yield strength, (b) UTS, and (c) elongation.

(a)

(b)

(c)

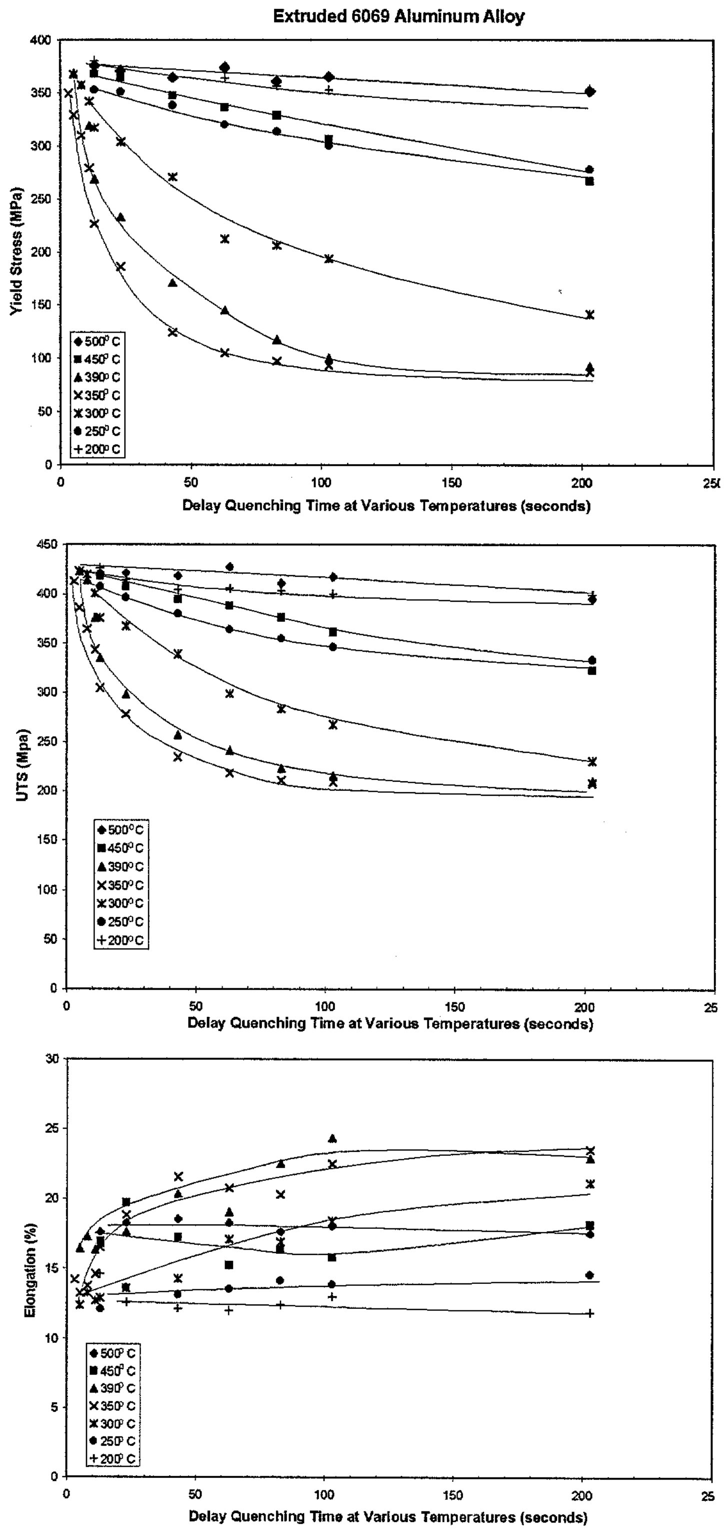
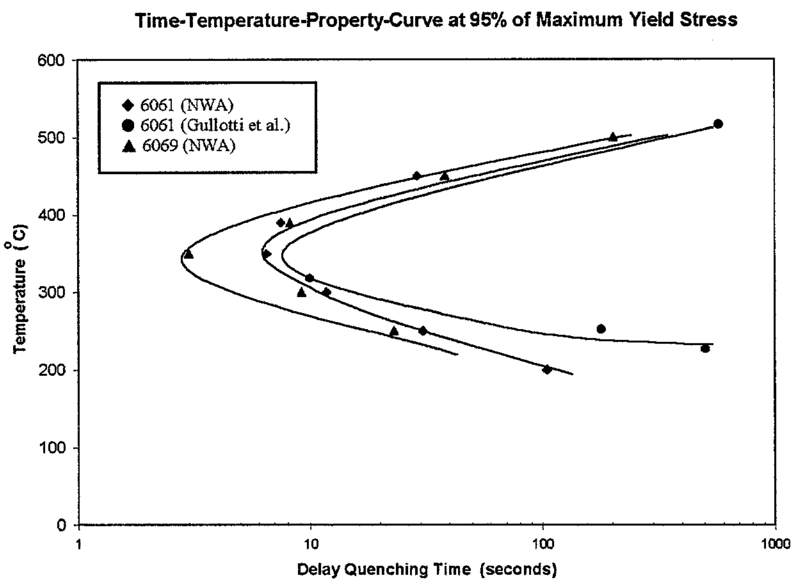


Figure 2. The effect of delayed quenching on the 6061-T6 (a) yield strength, (b) UTS, and (c) elongation.

(a)



(b)

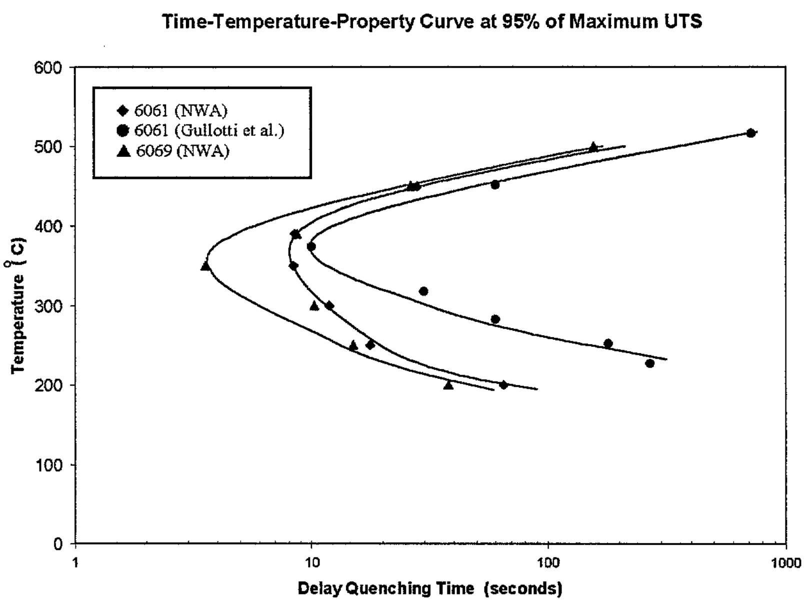


Figure 3. The time-temperature (a) yield, (b) UTS behavior of 6061-T6 and 6069-T6. Earlier work [3] on the 6061-T6 is also indicated.